#48

Department of Agriculture and Fisheries for Scotland in Association with the Atlantic Salmon Trust

# The Behaviour of Adult Atlantic Salmon Ascending the Rivers Tay and Tummel to Pitlochry Dam

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# The Behaviour of Adult Atlantic Salmon Ascending the Rivers Tay and Tummel to Pitlochry Dam

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**(Employed by the Atlantic Salmon Trust)**

## Introduction

The installation of hydro-electric power stations (HEPS) on a number of Scottish salmon rivers has led to concern (Calderwood, 1930; Menzies and Pentelow, 1965) for the fate of ascending Atlantic salmon (*Salmo salar* L.) and migratory trout (*Salmo trutta* L.). However, only a few studies have sought to establish the effects of these developments upon migratory fish (Pyefinch and Mills, 1963; Mills, 1968; Struthers, 1985).

Radio-telemetry has been used in several recent studies to establish the patterns of movement of individual salmon during their migration through estuaries and rivers (Hawkins and Smith, 1986; Potter, 1988; Solomon and Potter, 1988; Aprahamian, Strange, and Dimond, 1988; Laughton, 1989; Webb and Hawkins, 1989; Webb, 1989).

Webb (1989) reported the movements of radio-tagged grilse in the River Tay, Perthshire, during the summer of 1987. The principal objective of the present study, conducted in 1988, was to observe the behaviour of adult salmon in the River Tay and to determine those factors affecting their migration up stream. Particular attention was focussed on the detailed movements of radio-tagged salmon and grilse ascending the Rivers Tay and Tummel to the area of the HEPS at Pitlochry dam.

## Pitlochry Dam

Webb's (1989) description of the River Tay System (see Fig. 1) is supplemented here by an account of Pitlochry dam summarized from Calderwood (1946), Aitken, Dickerson and Menzies (1966), and Sturrock (1989).

The dam with an integral power station was brought into service in 1950, impounding the combined waters of the Rivers Tummel and Garry (Fig. 1) to form Loch Faskally. Pitlochry dam (Fig. 2) is of a gravity type, 145 m long and 16.5 m above the river bed, constructed to modulate irregularities in the flow caused by the varying discharges from other hydro-electric generating stations further up stream.

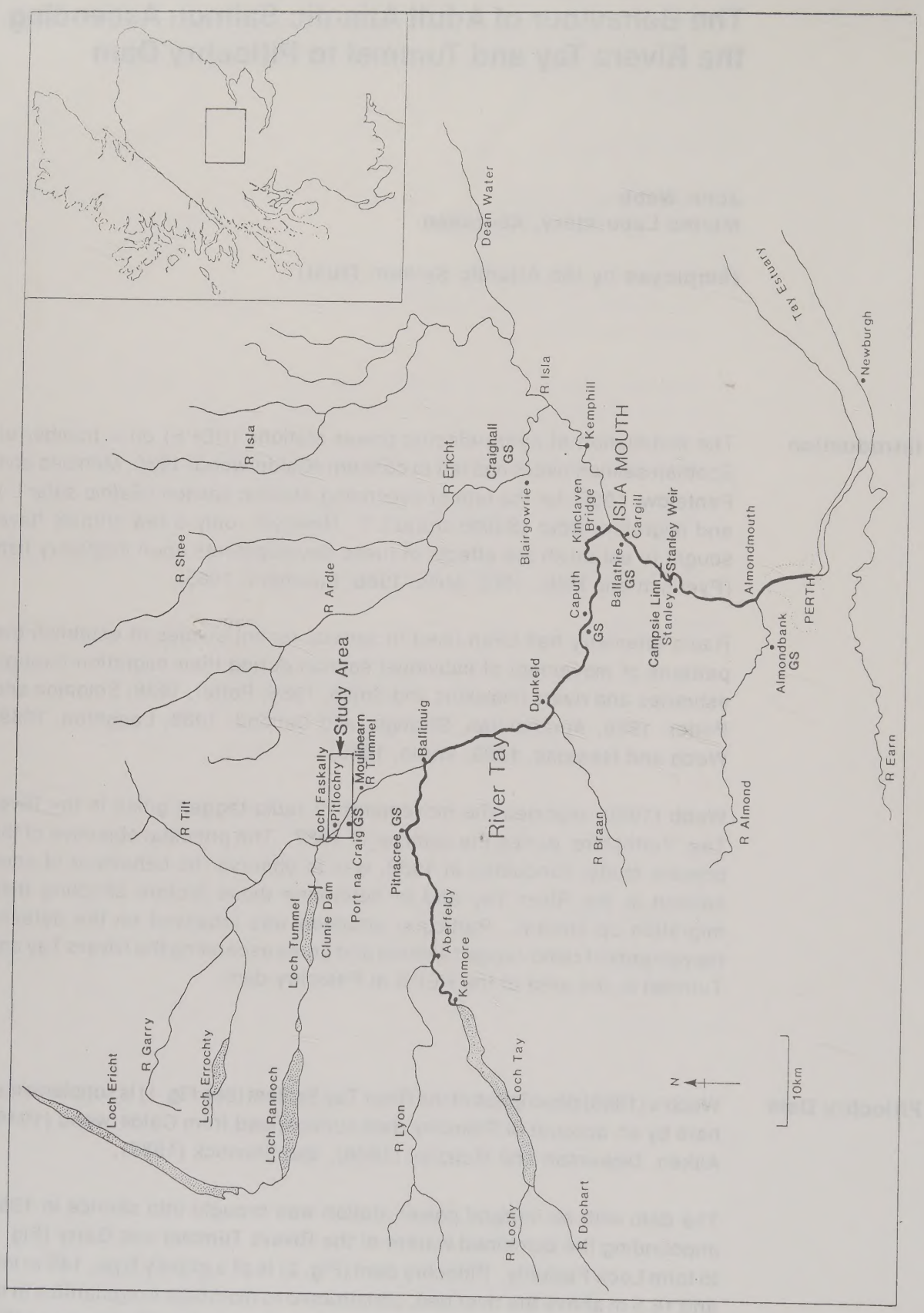


**Figure 1.** **The River Tay catchment showing the main tributaries, lochs, and positions of flow gauging stations (GS).**

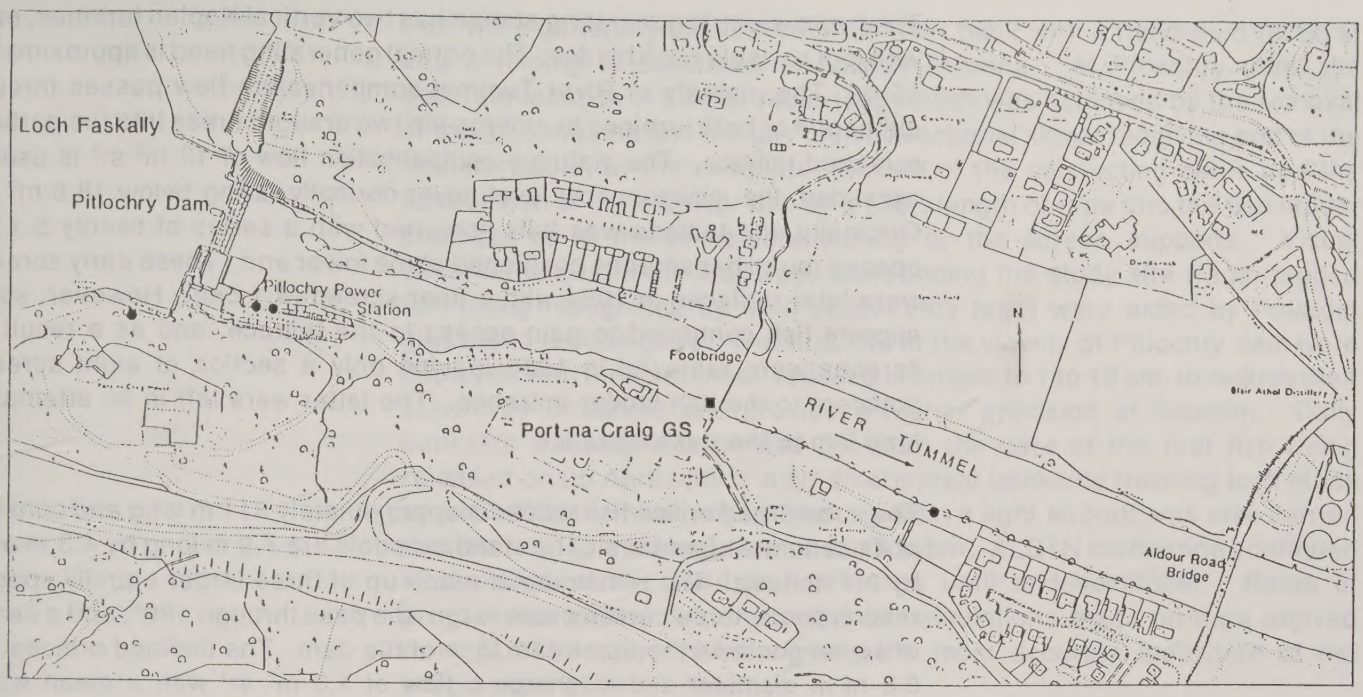


**Figure 2(a).** **Location map showing Pitlochry power station and dam, and the guaging station at Port-na-Craig on the River Tummel. The positions of ALSTNs ( • ) are also shown. This map is Crown Copyright reserved, reproduced from an Ordnance Survey map (1983; scale 1:10,000) with the permission of the Controller of Her Majesty's Stationery Office.**

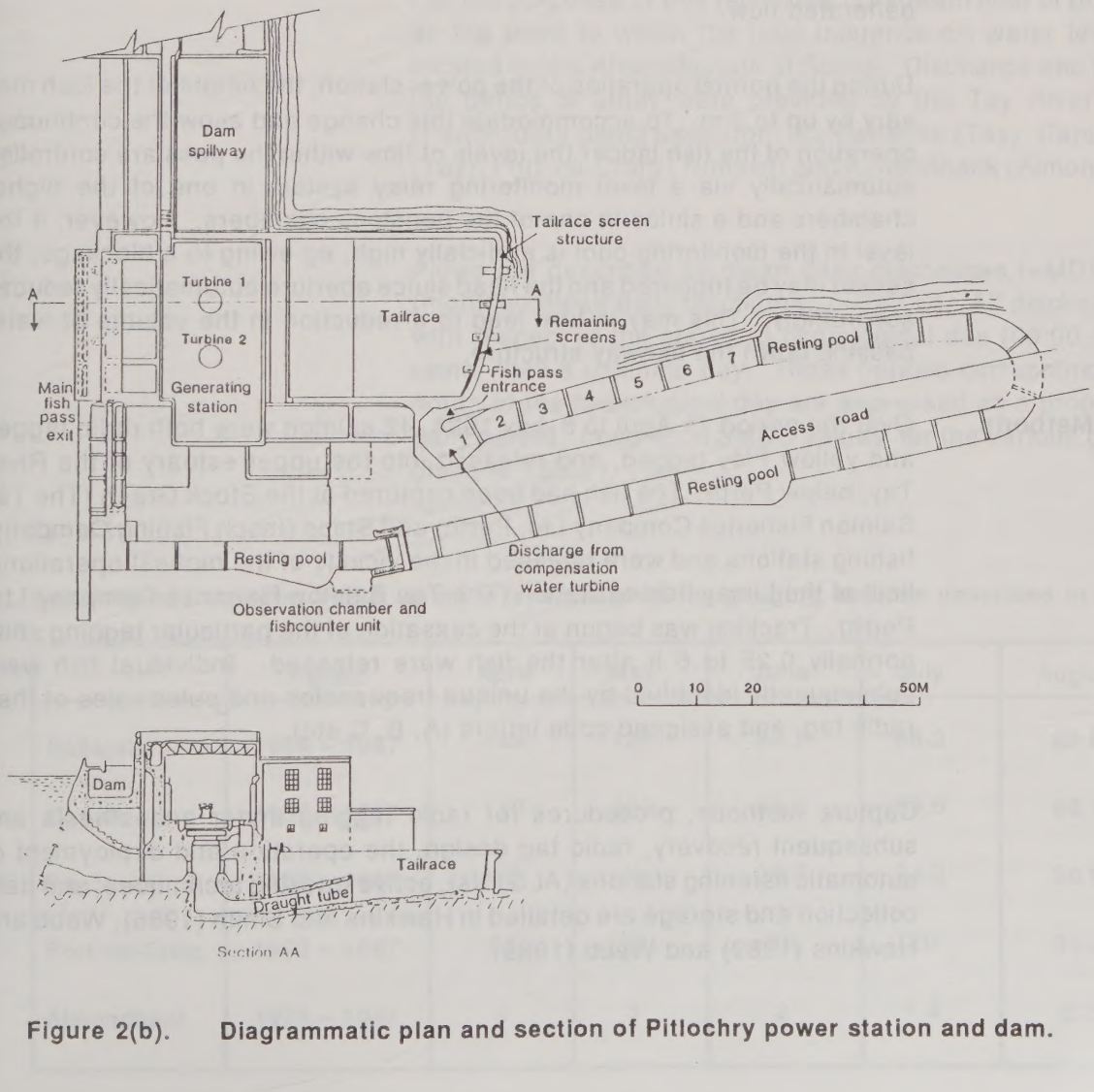


**Figure 2(b).** **Diagrammatic plan and section of Pitlochry power station and dam.**

The hydro-electric generating station has two vertical Kaplan turbines, each with four variable pitch blades. The normal generating head is approximately 15 m. The majority of River Tummel compensation flow passes through either one or both turbines to emerge via two draught tubes into the partially screened tailrace. The statutory compensation flow of 13 $m^3 s^{-1}$ is usually exceeded, the minimum flow level never normally falling below 18.6 $m^3 s^{-1}$. Originally, the tailrace was fully screened with a series of twenty 5.1 cm spaced round bar screens positioned at the lower end. These early screens were later replaced in 1954 with a finer screen (4.1 cm). However, some migrant fish continued to gain access to the tailrace, and as a result 12 screens were removed in 1956 leaving only a section of eight screens adjacent to the fish ladder entrance. The latter were left in an attempt to lead fish to the pass entrance.

The submerged orifice fish ladder is approximately 311 m long and consists of 34 concrete chambers. The standard pools are 7.9 m long by 4.3 m wide by 2.1 m deep. The remainder is made up of three larger equally spaced resting pools, three curved pools to turn the pass through 180°, and a series of seven pools on the up-stream face of the dam. The inclined orifices are 0.8 m in diameter and discharge a flow of 1.3 $m^3 s^{-1}$ with a mean water velocity of 2.4 m $s^{-1}$. The rise between adjacent pools is ca 0.46 m and the depth of the chambers approximately 2.44 m. The flow descending through the fish pass is normally *ca* 1.36 $m^3 s^{-1}$ though this is augmented by a further 0.6 $m^3 s^{-1}$ emerging from the small compensation turbine which discharges directly into the entrance chamber of the pass. The total flow emerging from the fish pass entrance never exceeds one tenth of the main turbine-generated flow.

During the normal operation of the power station, the height of the loch may vary by up to 3 m. To accommodate this change and allow the continuous operation of the fish ladder the levels of flow within the pass are controlled automatically via a level monitoring relay system in one of the higher chambers and a sluice in one of the penstock chambers. However, if the level in the monitoring pool is artificially high, eg owing to a blockage, the sensor may be triggered and the head sluice aperture automatically reduced accordingly. This may in turn lead to a reduction in the volume of water passing down the fishway structure.

## Materials and Methods

Over the period 25 April to 8 July 1988, 42 salmon were both radio tagged and yellow Floy tagged, and released into the upper estuary of the River Tay, below Perth. The fish had been captured at the Stock Green (The Tay Salmon Fisheries Company Ltd, Perth) and Ships (Insch Fishing Company) fishing stations and were released in the vicinity of the highest operational limit of the Limey fishing station (The Tay Salmon Fisheries Company Ltd, Perth). Tracking was begun at the cessation of the particular tagging shift, normally 0.25 to 6 h after the fish were released. Individual fish were subsequently identified by the unique frequencies and pulse rates of their radio tag, and assigned code letters (A, B, C etc).

Capture methods, procedures for radio tagging under anaesthesia and subsequent recovery, radio tag design, the operation and deployment of automatic listening stations (ALSTNs), active tracking techniques, and data collection and storage are detailed in Hawkins and Smith (1986), Webb and Hawkins (1989) and Webb (1989).

Fish were generally tracked from the river bank with a hand-held receiver and a folding bi-directional H-Adcock antenna. At Pitlochry dam, the accurate location (<5 m) of radio-tagged fish was achieved by the removal of the antenna unit and the use of the directional signal receiving end of the co-axial cable, or the complete removal of the connecting cable and the suspension of the receiver unit by a short length of rope into the fish ladder chamber or in the immediate vicinity of the screen supports. Visual observations from the walkways surrounding the study site (radio-tagged fish being recognised by their yellow Floy tags) were aided by Polaroid glasses to reduce glare. The ALSTNs in the vicinity of Pitlochry dam were deployed with their antennae reduced in length to 1 to 10 cm, to reduce their sensitivity threshold and provide a higher precision of location. Daily bankside tracking was carried out from the date of the first fish being released on 25 April until 8 July. Intermittent bankside tracking took place up until 30 November, whilst tracking from a light aircraft was also carried out, the last flight taking place on 29 October. ALSTN monitoring continued in the area of the Tay/Isla confluence until mid-November. Rates of progression for the fish are based on calculations made on data derived from ALSTNs only, thereby giving the most accurate indication of net progression in either direction.

The movements of fish are expressed in terms of the linear distance up stream from a standard datum point at Elcho Castle, near Perth (OS. Grid Reference, 316441 721316; Fig. 1), unless otherwise stated.

For the purposes of this report the up-stream limit of the estuary is defined as the point to which the tidal influence on water level extends, and is located below Almondmouth at Scone. Discharge and water level data for the period of study were provided by the Tay River Purification Board (Perth), data being used from the Ballathie (Tay), Caputh (Tay), Pitnacree (Tay), Port-na-Craig (Tummel) and Almondbank (Almond) gauging stations.

Flows are described by mean daily discharges (=MDD) and by summary (monthly) mean daily discharges (=SMDD). All discharge calculations are with respect to the standard hydrological day (09:00 GMT—09:00 GMT), rather than a calendar day. Those periods corresponding to less than six hours of the hydrological day are expressed as a proportion of the former daily period. Long-term SMDD values for the various gauging stations are given in Table I.

**Table I**

**Summary of long-term SMDD (in $m^3 s^{-1}$) recorded at the gauging stations described in the text**

| | Period | April | May | June | July | August | September |
|---|---|---|---|---|---|---|---|
| Ballathie | 1958 – 1987 | 149 | 126 | 84.7 | 66.2 | 85.6 | 121 |
| Caputh | 1958 – 1987 | 119 | 102 | 68.6 | 54.5 | 69.1 | 100 |
| Pitnacree | 1958 – 1987 | 47 | 41 | 28.6 | 24.2 | 30.0 | 45.6 |
| Port-na-Craig | 1973 – 1987 | 61 | 49 | 30 | 26 | 33.6 | 53.8 |
| Almondbank | 1973 – 1987 | 4 | 3 | 2 | 1.4 | 2.3 | 3.9 |

In the summer of 1989 studies were undertaken to establish whether radio tags would move down stream when liberated into the main flow emerging from Pitlochry dam. On 6 July, seven brightly painted radio tags were released into the river Tummel. Four radio tags were released into the main generating flow emerging from turbine unit No. 2 in the lower end of the tailrace, approximately 3 m up stream from the former screen positions. The other three radio tags were released in the centre of the main river channel immediately below the footbridge at Port-na-Craig. The movements of all seven radio tags were monitored by the radio-tracking procedures described earlier, and where possible, by visual observation.

## Results

Thirty-three of the 42 tagged fish were tracked as far as Almondmouth or higher, the others being recaptured at netting stations or by rods. Twenty-two of the migrants were tracked to areas within the river Tay and its tributaries, namely, the rivers Lyon, Isla, Ardle and Shee. The remaining eleven fish which ascended the lower Tummel to the area of the dam at Pitlochry (Figs 1 and 2) are the subject of the rest of this report. Details of these fish are given in Table II.

### Movements Up Stream from the Release Area and through the River Tay

The movements of the 11 fish (A—K) are shown in Figure 3. Summary mean daily flows recorded at the Ballathie, Caputh and Port-na-Craig gauging stations are also shown.

Movement from the release area to the Almondmouth ALSTN (Fig. 1) took 5.5—50.4 h (mean, 19 h). The timing of ascent from the release area through the head of tide at Scone and past the ALSTN at Almondmouth (Fig. 1) tended to dictate the timing of subsequent movement within the lower river to areas ranging from Stanley to Islamouth (Fig. 1). The time taken to ascend from the respective release points to the ALSTN at Almondmouth (indicative of the ground speeds attained) was compared with concurrent main-stem river discharges measured at Ballathie but no significant relationship was found. Similarly, the period of reception by the Almondmouth ALSTN (mean, 108 min.) was also compared with both main-stem Tay and River Almond daily and simultaneous flows but no relationship could be discerned.

In general, movement from the head of tide to the first stopping place within the lower reaches of the main-stem was continuous and conformed to a common general pattern. With the exception of Fish D (Table II), all ten fish moved through the lower reaches without any evidence of significant delay (>24 h) at potential obstacles such as Stanley weir or Campsie Linn (Fig. 1).

Migration through the reaches below the confluence with the River Isla occurred over a range of seasonal flows recorded at Ballathie, corresponding to 80—116% SMDD (April), 51—156% SMDD (May), 43—80% SMDD (June) and 53—216% SMDD (July). During the study period none of the fish was recorded to have entered the lower reaches of the river Isla. However, several fish remained in the area of the Tay/Isla confluence at Islamouth for varying periods of time.

Some movements occurred during the day as fish initially penetrated the upper tidal reaches of the estuary and the lower beats of the main-stem. Generally however, migratory activity took place from dusk to dawn, i.e., the movements were crepuscular and nocturnal (Fig. 4).

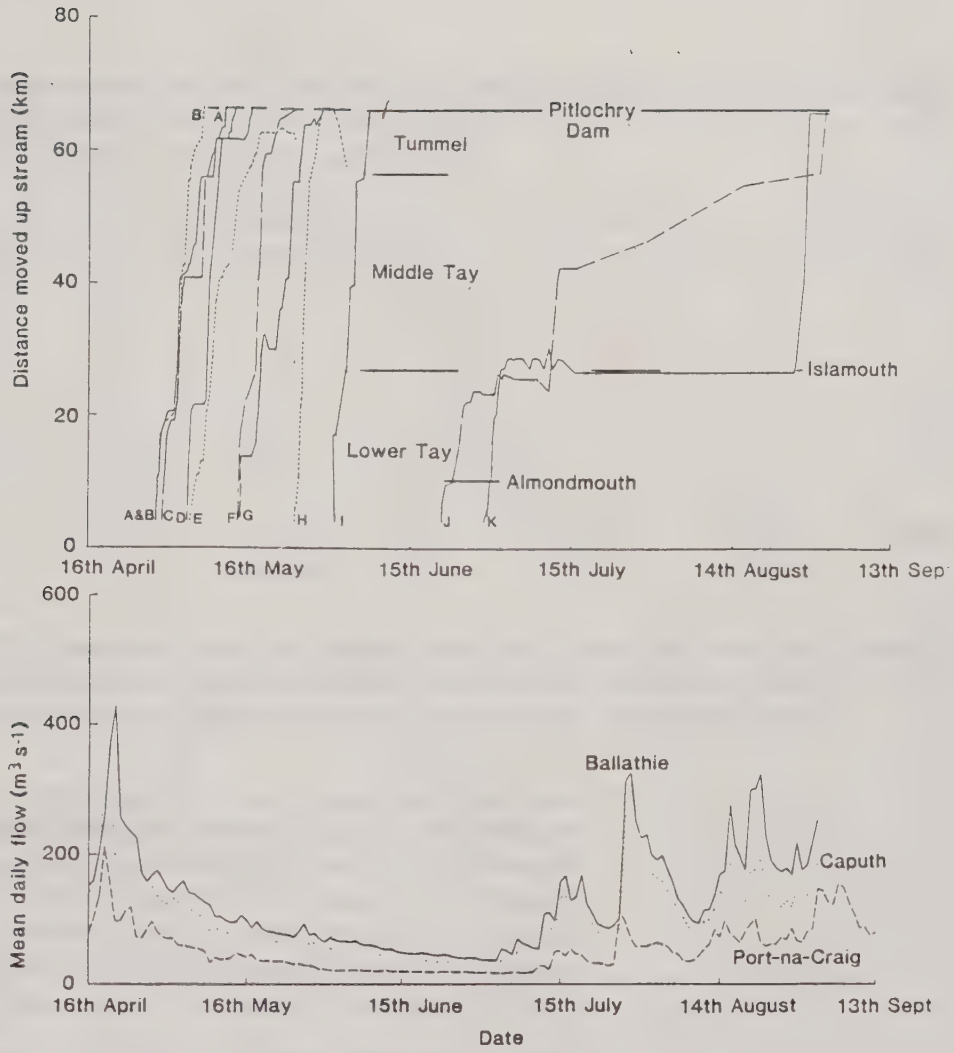


**Figure 3.** **The movements of 11 radio-tagged Atlantic salmon from their respective release areas in the upper estuary at Perth to Pitlochry dam near Port-na-Craig. MDD recorded at Ballathie, Caputh and Port-na-Craig are also shown.**

Migration through the middle reaches of the Tay to the confluence with the River Tummel at Ballinluig took place over seasonal discharges corresponding to 60—153% SMDD (May), 71—81% SMDD (June) and 155—257% SMDD (August), as recorded at Caputh. However, the movements of Fish J have been excluded from this analysis due to the sporadic nature of its ascent through this area of the river in July.

Progress through the middle reaches (Islamouth to the Tay/Tummel confluence; Fig. 1) took place in a stepwise fashion, migratory periods alternating with stationary periods. Distances covered during each migratory period in travelling from the Tay/Isla confluence to the confluence of the rivers Tay and Tummel at Ballinluig (Fig. 1) ranged from 0.72 km to 15.2 km (mean, 6.1 km). Fish moving from Islamouth into the middle reaches of the Tay generally covered the largest distance per migratory period ( > 5 km). An exception to this pattern was shown by Fish K which during significantly elevated flows on 27 August (Fig. 3), migrated from Caputh to Port-na-Craig (22 km) in *ca* 16.5 h.

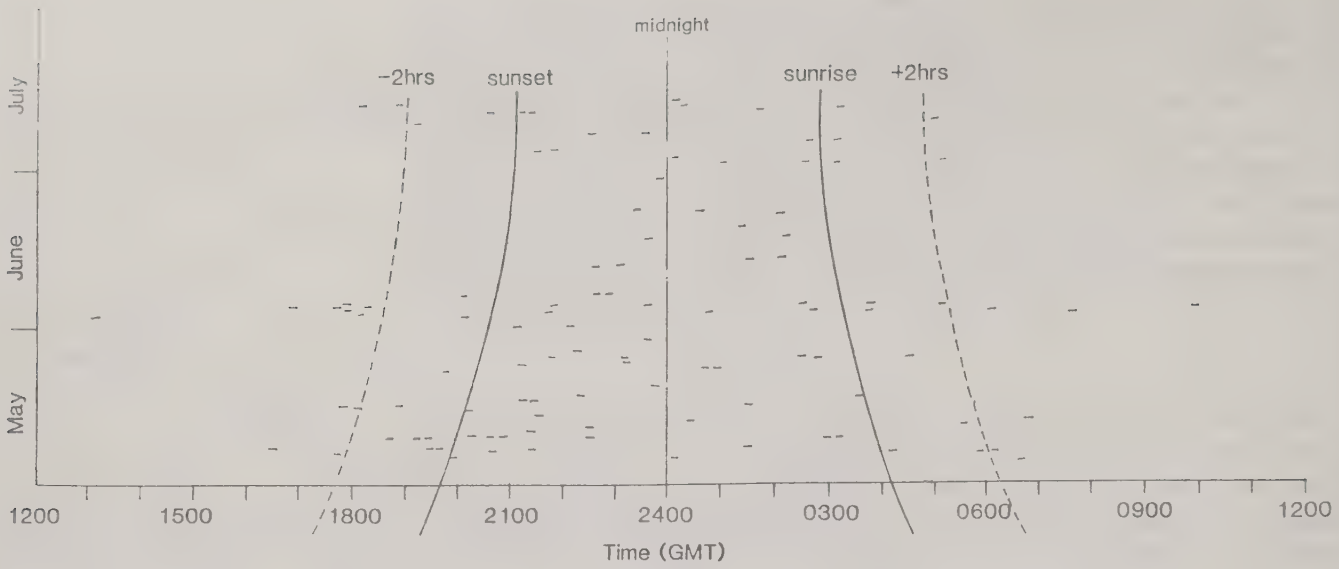


**Figure 4. The time of day when fish were recorded migrating up stream in the River Tay from Islamouth to the Junction with the Tummel; each point indicates the time at which a radio-tagged fish passed an ALSTN. The change in the times of sunset and sunrise are also shown.**

Individual up-stream movements initiated from Islamouth into the middle reaches of the Tay were significantly correlated ($P<0.01$ and $P<0.05$ respectively) to the MDD recorded over the previous 24 h, measured at Ballathie and Caputh in each case. The distances travelled were also compared with the level of flow recorded at the time that up-stream movement began (movement being monitored at the Meikleour House ALSTN), but no significant relationships were found.

Times of passage through the ALSTNs positioned at Almondmouth (10.9 km), Islamouth (26:5 km): Meikleour House (28.48 km) and Ballinluig (57.6 km) are summarised in Table II. With the exception of Fish J and K, movement from Almondmouth to the junction at Ballinluig took from 2 to 10.5 d (mean, 7.5 d). Temporary halts occurred in an area of recognised "holding" pools within the Kercock, Murthly, Dalguise and Kinnaird beats.

Behaviour at the Tay/ Tummel Confluence and Timing of Entry to the Lower Reaches of the River Tummel

The timing of entry to the lower reaches of the River Tummel, as indicated by the loss of reception by the ALSTN positioned at the confluence, is shown in Table III. Both the approach to the confluence from Kinnaird and subsequent entry to the Tummel took place during the hours of darkness (Tables II and III). The recorded period of reception at the confluence area was compared with discharges in both the Rivers Tay and Tummel, but no relationships were found. Entry and penetration of the lower Tummel occurred over a range of seasonal flows representing 61% to 113% SMDD (mean, 78%) in May, 66% SMDD (June) and 193—256% SMDD (August) (Tables II and III).

The distance travelled up stream by each fish during the single movement from the confluence at Ballinluig into the lower reaches of the river Tummel was compared with both Tay (measured at Pitnacree), and Tummel (Port-na-Craig) discharges but no relationships were found. Only the movements of those fish that had previously remained in the area below the junction for more than 6 h were considered. Fish E was recorded as entering the upper Tay (15.5.88; 19.30) before it entered the Tummel. It penetrated *ca* 0.3 km up stream before returning to the confluence pool at 01.28 the next morning. This activity took place over flows corresponding to *ca* 94% of the MDD measured at Pitnacree and 76% of the MDD at Port-na-Craig. The movevemnt movement was not associated with a significant increase in flow in either the Tay or the Tummel on that day. Fish E subsequently entered and ascended the lower Tummel at 01.44 the same day.

Table II

**Summary data for 11 radio-tagged salmon tagged and released in the upper Tay estuary, and the timing of their ascent through the lower and middle reaches of the River Tay to the confluence with the River Tummel at Ballinluig (28 April — 28 June 1988). All times are GMT**

| Fish | Sex | Weight (kg) | Release | | Almondmouth | | Islamouth | | Ballinluig | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | date | time | date | time | date | time | date | time |
| A | F | 5.4 | 28.4 | 13.34 | 28.4 | 20.38 | 2.5 | 09.55 | 7.5 | 11.06 |
| B | F | 5.2 | 28.4 | 14.55 | 29.4 | 02.42 | 2.5 | 18.12 | 4.5 | 16.38 |
| C | * | 5.3 | 29.4 | 19.00 | 30.4 | 04.11 | 2.4 | 15.35 | 8.5 | 22.34 |
| D | * | 4.9 | 04.5 | 09.16 | 4.5 | 13.50 | 7.5 | 21.25 | 9.5 | 20.50 |
| E | M | 5.9 | 04.5 | 18.09 | 6.5 | 04.14 | 8.5 | 20.35 | 15.5 | 17.54 |
| F | F | 7.0 | 13.5 | 18.19 | 13.5 | 21.39 | 16.5 | 22.41 | 18.5 | 22.18 |
| G | F | 8.5 | 13.5 | 17.40 | 14.5 | 05.00 | 17.5 | 22.30 | 24.5 | 18.56 |
| H | F | 5.8 | 31.5 | 08.50 | 25.5 | 01.48 | 25.5 | 11.05 | 27.5 | 02.38 |
| I | F | 7.3 | 31.5 | 18.35 | 31.5 | 23.54 | 2.5 | 21.45 | 5.6 | 22.34 |
| J | F | 5.4 | 20.6 | 21.15 | 23.6 | 22.52 | 10.7 | 23.15 | 29.8 | 21.20 |
| K | M | 4.0 | 28.6 | 17.17 | 30.6 | 02.52 | 2.7 | 18.50 | – | – |

* fish with underdeveloped secondary sexual characteristics.

### Ascent of the River Tummel to the Area below Pitlochry Dam

The timing of migratory activity within the Tummel, as recorded by a number of ALSTNs positioned between the confluence at Ballinluig and a point *ca* 630 m from the dam-base, is shown in Figure 5. 76% of the activity recorded took place during the late afternoon, early morning and night. There were some short-range movements within the larger pools coinciding with the wading activities of anglers (Fish A; on 11.5.88; at 13.50). Some sustained migratory activity by Fish K took place during a period of greatly elevated seasonal discharge between 25 July and 27 August (the end of the study period). The daily timings of the movements recorded on the ALSTNs were compared with earlier timings recorded during the ascent of the main-stem Tay from Islamouth to Ballinluig, but no significant differences were found. However, distances covered per migratory period ranged from 0.56 to 9.16 km (mean, 3.1 km). These movements were significantly shorter than earlier movements within the River Tay ($P<0.05$).

Ascent from the Tay/Tummel confluence to Pitlochry dam by the more active fish took 0.4 to 6.6 d (mean, 3 d). Fish E took 22 days to cover the same distance, as it stopped in a series of pools near Moulinearn. The stops took place over discharges ranging from 21.5 to 47 $m^3 s^{-1}$ corresponding to seasonal flows of 46—96% SMDD (May) and 71—76% SMDD (June). The more active migrants ascended the lower Tummel over a range of discharges (21.7 $m^3 s^{-1}$ to 118.6 $m^3 s^{-1}$) representing flows of 50.6—120% SMDD (May), 72—75% SMDD (June) and 174—352% SMDD (August)).

Table III

**Summary data of initiation of entry to the River Tummel by radio-tagged salmon from the confluence with the River Tay to the area below Pitlochry dam. All times are GMT**

| Fish | Date and time at confluence | Reception period (h:min) | Tay discharge $m^3 s^{-1}$ | (MDD) | Tummel discharge $m^3 s^{-1}$ | (MDD) | MIN[t] |
|---|---|---|---|---|---|---|---|
| A | 7.5 | 0:12 | 39.4# | (37.7) | 55.5# | (54.6) | 47.5 |
| B | 4.5 | 0:14 | 43.7 | (42.9) | 49.0 | 57.9) | 48.7 |
| C | 8.5 | 0:22 | 38.1 | (36.0) | 31.9 | (33.6) | 28.9 |
| D | 9.5 | 0:14 | 36.2 | (34.0) | 32.8 | (42.0) | 30.5 |
| E* | 15.5 | 0:02 | 28.0 | (27.7) | 43.3 | (42.2) | 35.2 |
| F | 18.8 | 0:10 | 85.9 | (73.8) | 86.3 | (81.1) | 68.5 |
| G | 24.5 | 0:06 | 25.7 | (28.1) | 31.0 | (31.1) | 29.4 |
| H | 27.5 | 0:04 | 25.7 | (29.1) | 30.0 | (28.7) | 27.9 |
| I | 05.6 | 0:16 | 21.7 | (22.1) | 20.2 | (21.9) | 21.7 |
| J | 29.8 | 5:44 | 64.2 | (66.1) | 64.8 | (65.2) | 46.0 |
| K | - | - | - | - | - | - | - |

\# Estimated level of flow at time of entry to the River Tummel.
[t] Lowest level of flow recorded for the standard hydrological day.
* Fish temporarily entered the upper Tay.

The larger figures were associated with the high flows in the latter half of the study period. The median flow at which migratory activity was recorded (calculated for the month of May only) was *ca* 38.0 $m^3 s^{-1}$, corresponding to 77.5% of the respective SMDD.

Pitlochry Dam and Associated Fish Pass

The main features of the dam and its associated fish pass are shown in Figure 2(b).

During the period of observation in 1988, the two available turbines were operated in a number of ways: a) both turbines simultaneously generating for the greater part of a 24 h period (on 8 May and 10 May); b) intermittent operation of a single turbine (turbine no. 1; on 9 May); c) prolonged operation of a single turbine for several consecutive days (turbine no. 2; 3-7 May, and 11 May to 10 June inclusive).

The timing of the approach to the dam (recorded by an ALSTN *ca* 630 m down stream of the dam; Fig. 2) and the subsequent timing of the first reception of each tagged fish by an ALSTN positioned at the entrance to the fish pass are shown in Table IV. Turbine operations during the course of each observation are also indicated. The time lapse between the two observations was compared to total flows within the river, but no relationship was found.

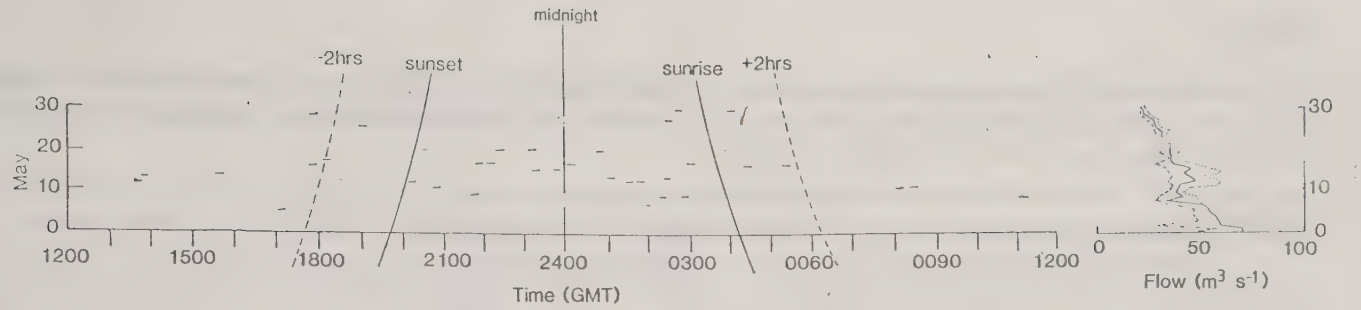


**Figure 5. The time of day when fish were recorded migrating up stream in the river Tummel to the ALSTN positioned *ca* 600 m below the dam. Mean ——, maximum ····· , and minimum ------ daily flows, together with the change in the times of sunset and sunrise are shown.**

*Behaviour of tagged fish below the dam*

Over the period 8 May to 6 September, detailed daily observations were made of the position of radio-tagged fish present below the dam. At the higher range of discharges (*ca* 35—40 $m^3 s^{-1}$), fish remained in areas away from the main emerging flow. Accordingly, they were not located within the partly enclosed tailrace (Fig. 2(b)) during the course of these higher flows. Channel traversing movements (on the down-stream side of the position of the former screens) were observed on four occasions, radio-tagged fish being observed moving from one side of the emergent flow to the other. On 31 August, Fish J was tracked traversing across the river channel from the down-stream corner of the northern wall of the tailrace to the entrance of the fish ladder, immediately below the tailrace screen supports (Fig. 2(b)) (12.28 — 13.16). Similarly Fish K behaved in a similar manner later that day (17.10 — 17.16), on the following day (13.50 — 14.30) and again on 2 September (13.30).

Over the period 28 May to 11 June, when a single turbine was operating, tagged fish were monitored entering the draught tube exit of the operating turbine (Table V, Fig. 2 (b)). Reception of the radio-tag signal was lost for periods up to 20 min. The intermittent loss of a radio-tag signal in this manner was recorded only at Pitlochry dam. Water temperatures recorded immediately below the dam site over the same period ranged from 8 to 19°C.

Visual observations confirmed that Floy-tagged fish moved forward from holding stations near the former screen positions towards the tailrace, where the flow was emerging. Fish approaching towards the operational northern draught tube (Turbine 1) (where most activity was recorded) tended to follow the surrounding walls rather than moving up stream via the centre of the channel. This pattern was not so evident with the southern draught tube. Untagged salmon and grilse in the same area were observed to accompany the ones which were tagged. At discharges of greater than *ca* 50 $m^3 s^{-1}$ the fish could no longer be seen. Temporary loss of radio reception was not recorded, however, suggesting that fish were not entering the draught tubes at high flows.

Individual tagged salmon remained in the area immediately below the dam for periods ranging from *ca* 0.6 to 43 d (Table VI). Fish A was last located in the area of the northern side of the tailrace on 12 May (12.34 GMT). A deterioration in the quality of the tag signal suggested that the tag had failed sometime after the last observation on that day.

Table IV

Timing of passage of radio-tagged salmon from an ALSTN *ca* 630 m from Pitlochry dam to the first reception at the entrance of the fish pass. The timing of subsequent movements into the 1st chamber of the fish ladder are also shown. All times are GMT

| Fish | Lower ALSTN reception | | | Passed mouth | | Time period (h:min) | Turbine | Flow range $m^3 s^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| | date | time | turbine | date | time | | | |
| A | 13.5 | 03.10 | 2 | 17.5 | 12.45 | 105:35 | 2 | 32.8 – 57.5 |
| B | 07.5 | 02.50 | 2 | 07.5 | 15.25 | 12:35 | 2 | 50.9 – 56.1 |
| C | 11.5 | 01.50 | 2 | 12.5 | 15.50 | 38:00 | 2 | 33.6 – 42.7 |
| | | | | 14.5 | 17.40 | 00:07 | 2 | 42.4 |
| | | | | 17.5 | 08.00 | 00:21 | 2 | 38.0 |
| | | | | 17.5 | 11.40 | 01:05 | 2 | 35.0 – 40.6 |
| D | 15.5 | 20.05 | 2 | 16.5 | 19.40 | 23:35 | 2 | 32.8 – 58.5 |
| | | | | 20.5 | 11.30 | 04:17 | 2 | 33.0 |
| | | | | 29.5 | 09.21 | 00:18 | 2 | 23.6 |
| | | | | 21.6 | 03.05 | 00:16 | 2 | 19.4 |
| E | 06.6 | 01.55 | 2 | 07.6 | 11.20 | 33:25 | 2 | 20.2 – 23.4 |
| | | | | 15.7 | 03.30 | 01:10 | 1 | 58.0 – 59.5 |
| F | 19.5 | 23.16 | 2 | 20.5 | 03.10 | 03:54 | 2 | 36.2 |
| G | 29.5 | 03.10 | 2 | - | - | - | 2 | 25.1 |
| H | 29.5 | 02.55 | 2 | 31.5 | 13.15 | 50:20 | 2 | 22.5 |
| I | 07.6 | 05.15 | 2 | 07.6 | 11.20 | 06:05 | 2 | 20.3 – 22.1 |
| J | 30.8 | 20.40 | 1&2 | 30.8 | 21.30 | 00:50 | 1&2 | 76.9 – 77.3 |
| K | 27.8 | 18.40 | 1&2 | 31.8 | 12.28 | 89:48 | 1&2 | 41.5 – 94.0 |

Those fish that successfully ascended the fish pass had previously remained below the dam for periods ranging from 0.6 to 43 d (mean, 23.7 d). Earlier arrivals spent longer periods below the dam, 31.5 d being the average for Fish B, C, D and E (Table VI). Figure 6 shows the distribution of ALSTN recorded activity in the area of the mouth of the fish pass over the period mid-May to early July.

Activity was distributed over the greater part of the day, but with an evident increase in reception frequency over the period *ca* 15.00—00.30 and 03.00—10.00 GMT over the greater part of the early summer period. The temporary curtailment of recorded activity in the early part of June, was not associated with an absence of tagged fish from the area, but rather, a tendency for those tagged fish present below the dam to remain on the northern side of the tailrace area or in pools some distance down stream (Figs 2 and 7).

Table V

**Timing of the entry and exit of radio-tagged salmon into the operational draught tube at Pitlochry dam (29 May–11 June 1988). All times are GMT**

| Fish | Date | Time observation began | Time of entry | Time of exit |
|---|---|---|---|---|
| A | 05.6.88 | 12.40 | 13.04 | 13.25 |
| | 05.6.88 | 11.45 | 12.10 | 12.21 |
| B | 05.6.88 | 13.00 | 13.44* | 13.45* |
| | 08.6.88 | 09.01+ | – | 09.04 |
| | 11.6.88 | 08.40+ | – | 08.44 |
| D | 29.5.88 | 10.00 | 10.21 | 10.39 |
| | 04.6.88 | 14.01+ | 14.01 | 14.12* |
| | 05.6.88 | 13.55+ | 13.55 | 13.39 - 13.47* |
| E | 06.6.88 | 12.30 | 12.52* | 12.59* |
| G | 29.5.88 | 15.41+ | 15.48* | 16.04 |
| H | 29.5.88 | 15.41 | 15.54 | 16.08 |

\+ Denotes radio signal absent at the beginning of the observation period.

* Denotes those movements visually confirmed from the surrounding walkway.

*Descent from the dam*

Descent from the area immediately down stream from the dam by more than *ca* 500m was recorded at an ALSTN positioned on the southern bank *ca* 630m below the dam (Fig. 2). These movements represent discrete instances of descent from areas immediately below the dam base, initiated outwith the reception area of the highest ALSTN (Fig. 2(a)). Three broad classes of the activity were recorded:

Class 1. Temporary fall-back to the holding pool below the footbridge (Fig. 2(a)).

Class 2. Temporary fall-back to the larger pools below the road bridge (Fig. 2(a)).

Class 3. Longer range down-stream movements.

Table VI

**Summary data for period of residence and ascent or fall-back of radio-tagged salmon below Pitlochry dam. All times are GMT**

| Fish | Period below dam (days) | Time and date at pass entrance | Time at pass exit | Final location on 30.11.88 |
|---|---|---|---|---|
| A | 30 | – | – | Tag failure (13.6.88) |
| B | 43 | 18.6.88 (06.10 – 06.15 | – | Garry* (09.9.88) |
| C | 4 | – | – | Ballathie |
| D | 37 | 22.6.88 06.05 | – | Upper Tilt* |
| E | 42 | 17.7.88 09.20 – 09.30 | 13.01 | Garry* |
| F | 4 | – | – | Estuary |
| G | 2 | – | – | Stenton |
| H | 2 | – | – | Stenton |
| I | 6 | – | – | Dunkeld |
| J | 0.6 | 31.8.88 10.25 – 12.20 | – | Tilt* |
| K | 20 | 15.9.88 13.30 | 16.30 | Errochry* |

* Denotes the destination of the radio-tagged fish which subsequently negotiated the fish pass.

Table VII summarises the timing and frequency of activity over the period 9 May to 9 June 1988. With the exception of Fish D, all tagged fish displayed one or more of the activities described above.

Figure 7 shows the timing of the events described in Table VII in relation to the cumulative emergent flows recorded by the gauging station at Port-na-Craig, and those major changes in turbine operation over the common period indicated, but not described, in Table VII. The various classes of descent from the dam were not associated with any particular level of flow or particular change in generating regime.

During long-range descent from the dam by five fish, the timing of passage down stream was recorded by a number of ALSTNs distributed along the lower Tummel and River Tay (Tables VIII and IX). These movements were discontinuous in nature. The timing of initiation through the first ALSTN positioned *ca* 630 m below the dam appeared to dictate the subsequent pattern of descent to areas within the main Tay. The movements took place at dawn or dusk, or at night, rather than at any other time of day (Tables VIII and IX). Upon attaining their final positions in the River Tay (Table VI) no further activity of any kind was recorded up to the end of the observation period (30 November).

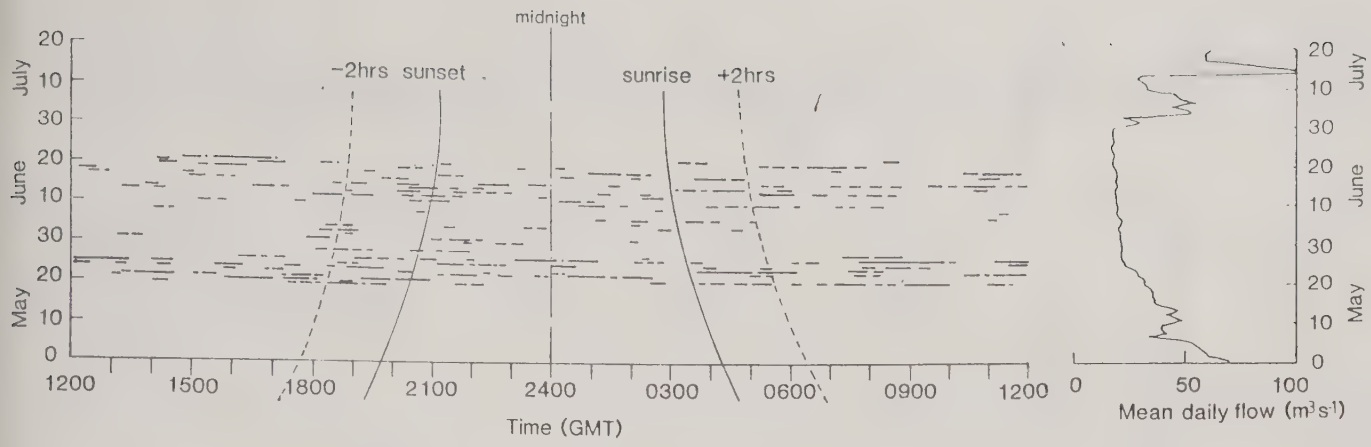


**Figure 6.** **The time of day when radio-tagged salmon were recorded in the vicinity of the fish-pass entrance at Pitlochry dam; each point indicates the time and duration of radio-tag signals received by the ALSTN at the fish-pass entrance (Fig. 2(b)). MDD at Port-na-Craig, and the change in the times of sunrise and sunset are also shown.**

**Table VII**

**Summary of the timing and associated activities of radio-tagged salmon descending from the base of Pitlochry dam (9 May – 9 June 1988)**

| Fish | Date | Time (GMT) | Class of movement | Turbine no | Discharge ($m^3$ $s^{-1}$) | (MDD) | Turbine change |
|---|---|---|---|---|---|---|---|
| A | 09.5.88 | 02.10 | 1 | 1 | 29.5 | (33.6) | – |
| B | 09.5.88 | 21.25 | 1 | 1&2 | 29.1 | (42.0) | – |
| | 10.5.88 | 01.45 – 02.00 | 1 | 2 | 37.8 | (38.5) | 1 to 2 (21.12 – 21.18) |
| | 11.5.88 | 14.00 | 1 | 2 | 35.3 | (39.3) | – |
| | 11.5.88 | 21.40 | 2 | 2 | 42.9 | (39.3) | – |
| | 14.5.88 | 21.30 – 22.51 | 2 | 2 | 28.8 | (45.5) | – |
| C | 15.5.88 | 21.45 | 3 | 2 | 37.8 | (42.2) | – |
| F | 20.5.88 | 21.30 – 21.36 | 1 | 2 | 28.9 | (35.8) | – |
| | 21.5.88 | 20.55 – 21.10 | 2 | 2 | 33.3 | (36.3) | – |
| | 22.5.88 | 01.00 | 3 | 2 | 38.8 | (36.3) | – |
| G | 30.5.88 | 02.10 | 3 | 2 | 30.7 | (23.6) | – |
| H | 30.5.88 | 00.50 – 01.15 | 1 | 2 | 30.7 | (23.6) | – |
| | 30.5.88 | 14.35 – 15.45 | 2 | 2 | 22.1 | (23.4) | – |
| | 31.5.88 | 02.45 | 2 | 2 | 23.1 | (23.4) | – |
| | 01.6.88 | 02.55 | 3 | 2 | 22.1 | (21.8) | – |
| I | 08.6.88 | 00.30 – 01.30 | 1/2 | 2 | 22.1 | (21.3) | – |
| | 08.6.88 | 09.15 – 09.25 | 1 | 2 | 20.7 | (21.3) | – |
| | 09.6.88 | 00.20 – 00.50 | 1 | 2 | 21.2 | (21.2) | – |
| | 09.6.88 | 02.55 | 3 | 2 | 21.2 | (21.2) | |

* Denotes timing of any change in the operation of turbines 1 or 2.

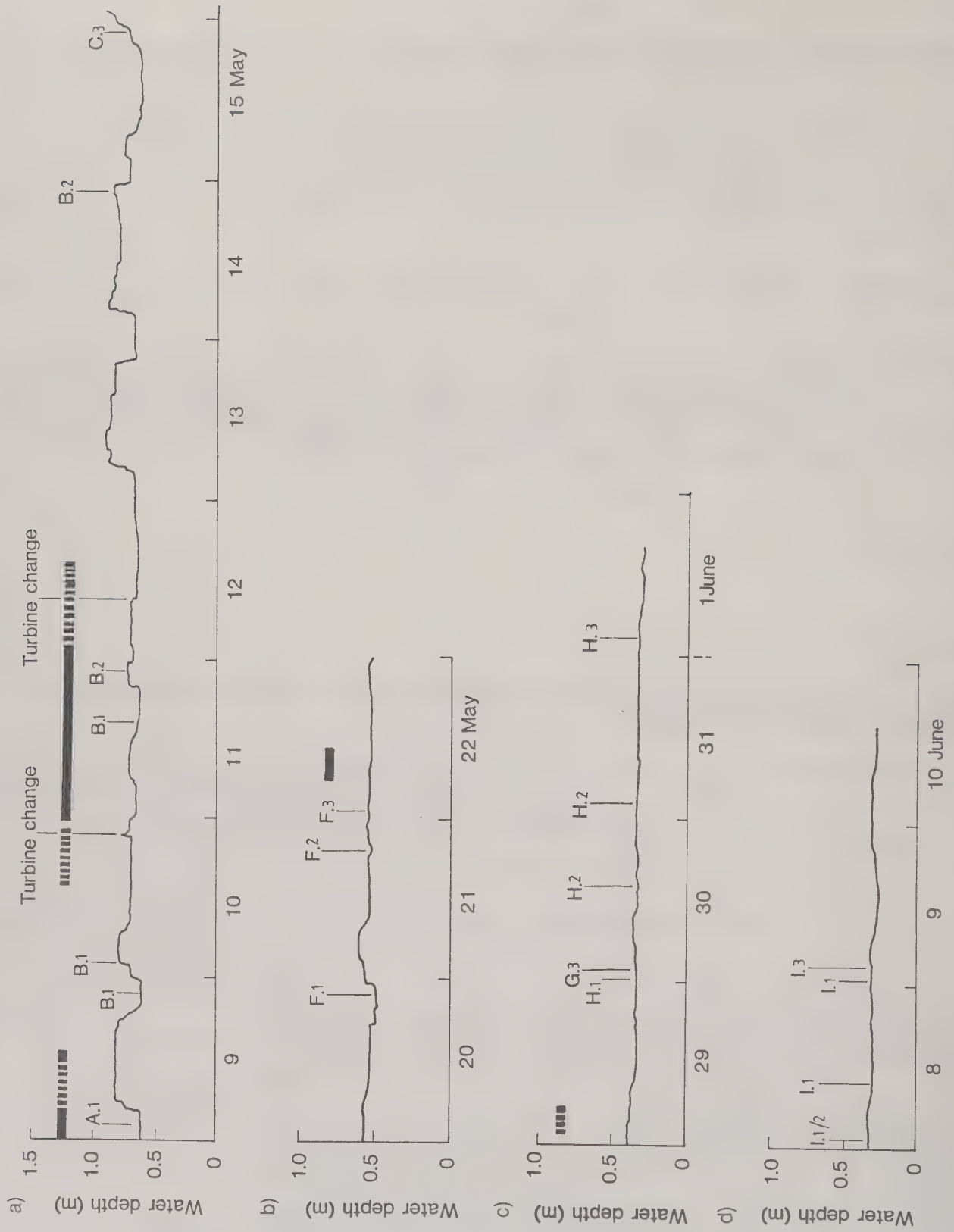


Figure 7. Timing of the descent of radio-tagged salmon from the base of Pitlochry dam in relation to water levels recorded at Port-na-Craig. The timing of disruptions to the normal operation of the fish pass (Table X) is indicated by the horizontal bar.

a) 9—15 May
b) 20—22 May
c) 29 May — 1 June
d) 8—10 June

Table VIII

**The timing of down-stream movement of three radio-tagged salmon (Fish C, F and G) from Pitlochry dam through ALSTNs positioned on the lower Tummel and River Tay. All times are GMT**

| | Fish C | | Fish F | | Fish G | |
|---|---|---|---|---|---|---|
| | date | time | date | time | date | time |
| Last observation at the dam | 14.5.88 | 22.45 | 25.5.88 | 02.00 | 30.5.88 | 03.10 |
| Ballinluig (junction pool) | 15.5.88 | 21.36 | 24.5.88 | 23.30 | 30.5.88 | 16.12 |
| Dalguise | – | – | – | – | – | – |
| Murthly | 17.5.88<br>-18.5.88 | 21.55<br>16.05 | 25.5.88 | 06.16 | 31.5.88 | 22.35 |
| Meikleour | 19.5.88 | 09.10 | 25.5.88 | 2.40 | | |
| Islamouth | 19.5.88 | 15.55 | – | – | | |
| Taymount | – | – | 26.5.88 | 06.50 | | |
| Fishponds | – | – | 27.5.88 | 01.35 | | |
| Almondmouth | – | – | 29.5.88 | 04.12 | | |

Table IX

**The timing of down-stream movement of two radio-tagged salmon (Fish H & I) from Pitlochry dam through ALSTNs positioned on the lower Tummel and the River Tay. All times are GMT**

| | Fish H | | Fish I | |
|---|---|---|---|---|
| | date | time | date | time |
| Last observation at the dam | 1.6.88 | 0.1.35 | 13.6.88 | 14.40 |
| Ballinluig (junction pool) | 2.6.88 | 21.52 | 13.6.88 | 19.50 |
| Dalguise | – | – | 14.6.88 | 12.10 |
| Murthly | 6.6.88 | 09.20 | | |

Table X

**Summary of the timing and nature of interruptions to the normal operations of the fish pass at Pitlochry dam (9 May – 17 August 1988)**

| Date | Area of blockage | Notes |
|---|---|---|
| 09.5.88 | Orifice* | Pass drained and cleared on the same day. |
| 11.5.88 | Orifice* | Remained blocked all day. |
| 12.5.88 | Orifice* | Pass drained and 11.5.88 blockage cleared. |
| 18.5.88 | Penstock 'B' | Remained blocked all day. |
| 19.5.88 | Penstock 'B' | Pass drained and 18.5.88 blockage cleared. |
| 22.5.88 | Penstock 'B' | Gate closed/control manfunction continued until 26.5.88, whereupon pass drained. Pass reflooded at 13.15 (GMT). |
| 29.5.88 | Maintenance | Pass drained. Reflooded at 09.52 (GMT). |
| 0.2.8.88 | Orifice* | Pass drained, and orifice cleared on same day. |
| 17.8.88 | Orifices* | Pass drained at 06.00 (GMT), blockages cleared and reflooded at 12.00 (GMT). |

* Blockage owing to water-borne debris

*Behaviour of tagged fish in the area of the fish pass*

Over the period of observation, variations occurred in both the operational height of water within the fish pass from day to day and the level of turbulence generated within different chambers of the pass structure. Reductions in flow within the pass appeared to coincide both with the partial blockage of one or more of the integral orifices and with the lower range of water levels within the loch above. Water depth is continually monitored in one pool of an upper chamber (Fig. 2(b)), for the purposes of controlling an automatic sluice at the ladder head. However, this monitoring does not provide information on the range of discharges within the structure on any one day. An accumulation of floating and semi-submerged material was evident in the lower four chambers (Fig. 2(b)) up to the date of the last observation on 31 August. Over the period 9 May to 17 August (inclusive) routine operation of the fish pass was interrupted on a number of occasions (Table X).

Several of the instances of down-stream movement summarised in Table VII corresponded in timing with the interruptions to the normal operation of the fish pass. Flows emerging from the small compensation turbine discharging close to the entrance to the fish pass (Fig. 2(b)) remained constant over the duration of the study period.

*Approach to the fish pass and entry to lower chamber*

Table IV shows the frequency and timing of entrance to the mouth of the fish pass, ie entry to the first chamber (Fig. 2(b)), by tagged fish and their subsequent activity. Approach to this area did not take place at a particular time of day (Fig. 6). Similarly, activity at the entrance to the pass was not associated with any particular level of discharge from the turbines. Fish G was not recorded as having approached this area of the site (Table IV) despite being located in the tailrace area over the period 29 May (03.10 GMT) to 30 May (02.10 GMT) inclusive.

*Ascent of the fish pass*

Five tagged fish ascended the fish pass to enter Loch Faskally over the study period (Table VI). Of this group, two had already entered the pass entrance on at least one occasion (Table IV). Only in the case of Fish E and Fish K was the timing of emergence from the top of the fish pass into the loch monitored, passage through the pass structure taking 2 h 31 min. and 3 h respectively. However, circumstantial evidence showed that passage of the other three fish through the pass into the loch above took place in less than 6 to 10 h (Table VI).

Fish F entered the pass (on 22 May; at 12.10 GMT) and ascended to the level of chamber 6 (Fig. 2(b)). It then descended and subsequently left the pass 13 h 50 min. later (on 23 May; at 02.00 GMT). Its descent coincided with the blockage of the fish pass due to a malfunction in the operation of a control sluice, at the head of the pass (Table X). The fish was not recorded as approaching the pass entrance area again (Table VI). The emergent generating discharges associated with residence period of each tagged fish below the dam were compared with the subsequent discharges associated with entry and subsequent ascent of the pass, but no significant relationships were found.

Movements of Liberated Radio tags

Seven radio tags were released into the River Tummel below Pitlochry dam on 6 July (at 13.35 GMT). The total flow emerging from the dam at that time was 21.7 $m^3 s^{-1}$. Immediately after release, all tags sank at rates of *ca* 0.5—0.7 m $s^{-1}$. The furthest down-stream displacement recorded in those tags released in the tailrace was *ca* 8 to 10 m. In the second group, a displacement of *ca* 0.5—0.75 m from the point of entry at the water's surface to the final resting position on the river bed was recorded. No further down-stream movement was observed after the tags had come into contact with the river bed.

Further observations on 14 July showed that all tags had remained in the final positions recorded on 6 July. The total flow emerging from the dam over the intervening period varied between 19.7 and 27.0 $m^3 s^{-1}$.

## Discussion

### Movements Upstream from the Upper Estuary to the River Tummel

Broadly, the pattern of migratory activity from the release point below Perth to the vicinity of the dam can be divided into two main phases (1 and 2):

*Phase 1. Movements from the estuarine release site into the river*

After release, the fish generally undertook a sustained period of up-stream movement. The fish eventually stopped within a series of pools in the lower reaches of the main river between the head of tide at Scone and the Tay/Isla confluence at Islamouth. The initial phase of sustained activity took place over a range of seasonal flows and times of day. Fish entering the river early in the day normally continued to migrate up stream in daylight to the first halt. When fish entered the river later in the day, migratory activity continued through the evening into the hours of darkness.

An initial period of sustained ascent appears to be a characteristic of salmon entering the larger east coast salmon rivers in Scotland. Such activity has been recorded from fish ascending from the tidal reaches of both the rivers Tay and Dee (Hawkins and Smith, 1986; Webb, 1989). In the Tay the sustained movement commonly lasts less than 24—30 h from the passage through the area of the head of tide. The distance of river penetrated is perhaps influenced by a number of factors including the season, the position of confluence areas, the distribution of physical barriers, and river water temperatures. For those fish entering fresh water immediately after arrival in coastal waters, the intensity of previous oceanic migratory activity may also be important.

Entry to the river was recorded over a range of seasonal flows. The data obtained do not lend themselves to detailed consideration of the effect of river discharges on the entry of fish to the lower river. Nevertheless, tracking studies undertaken on the Tay in 1987 suggest that though water flow may stimulate the initiation of migration up stream from the estuary, it may not necessarily modulate subsequent migratory activity during the later stages of the initial sustained ascent (Webb, 1989).

*Phase 2. Movement after the first stop in the river*

A second phase of activity occurred after the first stop. In the absence of significant increases in discharge above the seasonal norm, subsequent movement tended to be confined to both crepuscular and nocturnal periods. Such a pattern of activity has been recorded during a number of other similar studies (Hawkins and Smith, 1986; Webb and Hawkins, 1989; Laughton, 1989; Webb, 1989). In this study, up-stream movement was recorded over a range of discharges, corresponding to varying proportions of long term average seasonal flows. The range of flows over which movement took place, in both the River Tay and the lower Tummel, was broadly consistent with those described for active phases of movement by other workers monitoring the movements of salmon in other rivers (Baxter, 1961; Peters, Farmer and Radford, 1973; Cragg-Hine, 1985). Peters *et al.* (1973) stated that "the rate of flow of a river is important, if not the dominant stimulus to the up-stream migration of fish". Most previous studies on the role of river flow on the migratory behaviour of adult salmon have tended to examine the effect of absolute levels or changes in flow on the gross migratory activity of fish (Pyefinch and Mills, 1963; Mills, 1968; Webb and Hawkins, 1989; Webb, 1989). Detailed analysis of episodes of fish movement in relation to different levels of flow have not been reported previously.

Movement up stream from the Tay/Isla confluence was recorded over a range of flows. Migratory behaviour within the Tay has been previously described for grilse (1 sea-winter salmon) tagged and released in June and July 1987. Many of those fish subsequently entered the River Isla having moved up stream to the confluence in a single movement lasting for 24—36 h upon leaving the estuary. The timing of entry to the Isla and subsequent sustained penetration of the lower reaches of the river corresponded with the arrival of spates descending the tributary to the confluence, rather than particular flow conditions pertaining within the Tay itself. In addition, the distance the fish penetrated the tributary appeared to depend on the prevailing level of flow in each case (Webb, 1989).

In the present study, an apparent correlation has been described between the mean level of flow measured over the previous 24 h at both the Ballathie and Caputh flow gauging stations and the subsequent distance of movements of tagged fish moving from the Tay/Isla confluence into the middle reaches of the Tay. Interestingly, a more significant level of correlation was obtained for flows measured below the confluence at Ballathie than for flows measured at Caputh. However, no such relationship was found between these same movements and the levels of flow at the time these movements were initiated. This observation suggests that the movement of fish from Islamouth represents a graded response to the previous experience of cumulative river flows rather than a response to the immediate flow within the tributary that the fish subsequently continued to ascend.

Movements in the River Tummel and at Pitlochry Dam

The general pattern of activity of radio-tagged fish ascending the lower Tummel was similar to that previously recorded within the River Tay. Ascent of the lower Tummel and subsequent approach to the dam occurred over a range of discharges. There was no indication that the regulated discharges from the dam resulted in any disruption of the general pattern of migratory behaviour recorded within the middle reaches of the Tay. The patterns of migratory behaviour were similar to those reported by workers on other rivers (Stewart, 1972; Dunkley and Shearer, 1982; Hawkins and Smith, 1986). However, the distance moved per migratory period and thus the over-all rate of progress up stream within the Tummel, was significantly lower than the former movements recorded within the Tay.

The differences recorded perhaps reflect the differences in the physical nature of the two channels rather than any single causative factor. Over-all, the movements observed in both areas were well within the range recorded within several other rivers (during comparable seasonal stages of migratory activity) which, unlike the Tay and Tummel, are unregulated (Hawkins and Smith, 1986; Laughton, 1989).

The radio-tagged salmon ascended to Pitlochry dam before significant numbers of untagged fish were recorded migrating through the fish pass. By monitoring the timing of recaptures of returning migrating adults previously tagged as smolts, Struthers (1984) showed that the fish of different sea ages of River Tummel origin entered and ascended the river at different times within a single migratory season. It is unlikely that the radio-tagged adults were the first fish to arrive at the dam during 1988. The majority of the salmon radio-tagged during the course of this study were 2 sea-winter fish rather than earlier running 3 sea-winter fish or summer entrants such as grilse. The results described here should be considered in an appropriate seasonal context, rather than being indicative of the behaviour of all salmon ascending to the dam at any other time. Similar studies undertaken over the same season but in other years may give different results.

The delay in the movement of either tagged or untagged fish through the fish pass may also reflect the thermal restrictions imposed on the burst-swimming capacity of salmon in the winter and early spring period (Menzies, 1931; Jones, 1959; Gardiner, 1971; Beach, 1984). The counter electrodes are positioned some distance up the fish pass. Therefore, the first recorded ascent of the fish ladder within any particular migratory season is likely to take place after initial attempts to ascend through the lower chambers of the ladder.

The time period between the initial approach to the dam by an individually tagged fish and its first detection in the general area of the fish-pass entrance was variable. Despite the lack of detailed data on the route taken in each case, it would appear that the fish-pass entrance is not the preferred area beneath the dam for migrants. There are, of course, large differences between the water flow emerging from the turbine draught tubes and the fish pass. During periods when the total flow emerging from the dam was less than *ca* 50 $m^3 s^{-1}$, both tagged and untagged fish appeared to be attracted to those areas within the tailrace affected by the large turbine discharges rather than the smaller flows emerging from the fish-pass entrance.

The passage of tagged fish from below the dam to the loch above was subject to a range of delays over the study period. Delays in the migration of salmon and trout have been reported for a range of HEPS and their associated fish passes (Liscom, Monan, Stuehrenberg and Wilder, 1985). However, it is likely that the activities of the fish in each case are both site and species specific, and therefore of little direct relevance to the behaviour recorded at Pitlochry dam.

To summarise, the observations in this study suggest two aspects of the behaviour of the fish which may account for the delays recorded:

i) A tendency for fish to remain within the tailrace, as a result of the direct influence of the main generating discharge, which emerges some distance from the fish-pass entrance.

ii) A tendency for fish to enter the lowest chamber of the fish pass without continuing to ascent the fish ladder.

A prominent feature of Pitlochry dam is the accessibility of the tailrace to migrating salmon. Much of the behaviour recorded during the course of this study appears to result from the attraction of fish to this area. However, it is clear that the strong tendency for tagged fish to remain within the channel some distance from the fish-pass entrance does not fully explain the delays recorded in fish ascending the fish pass, as many of the tagged fish were located several times in the vicinity of the ladder entrance and were subsequently recorded as having unsuccessfully attempted to ascend it. In the absence of more detailed observations on the behaviour of migrants at the mouth of the fish pass it is difficult to account for this behaviour. However, it may reflect the absence above the first chamber of additional flow from the small compensation turbine, which enters the bottom of the fish pass (and comprises approximately one third of the total flow).

The biological consequences of imposed delays upon migrating Atlantic salmon populations have yet to be assessed. Delays may be a normal feature of behaviour within a river system. The most common delays are those associated with the presence of various natural physical obstacles, most often waterfalls (Calderwood, 1909; Menzies, 1931; and Jones, 1959) or shallow water at the mouths of tributaries (Webb and Hawkins, 1989; Webb, unpublished observations).

In addition, delays have been recorded down stream of subsequent spawning positions (Jones, 1959; Hawkins and Smith, 1986) and within traditionally recognised "holding" pools dispersed within river systems (Calderwood 1909; Jones, 1959; Hawkins and Smith, 1986; Laughton, 1989; Webb 1989). Several conventional and radio-tagging exercises suggest that long periods of inactivity are a prominent feature of riverine behaviour in all bu the very latest ascending runs of fish within a single migratory season (Calderwood, 1909; G.W. Smith, A.D. Hawkins, J.H. Webb and A.D.F Johnstone, unpublished observations). Within unobstructed channels radio-tagged individuals may remain within a particular pool for periods ranging from a number of days to several months (Hawkins and Smith 1986; Laughton, 1989; Webb, 1989). These fish may become active periodically, but often for only a few hours in any one day. Temporary excursions may be made to different areas of the channel and to nearby pools. These movements often appear to be associated with changes in flow, the time of day, disturbance, and the movement of other fish through the same area of the river channel (Webb, unpublished observations).

It is clear that tagged fish showed a significant increase in activity upon arrival at the dam, despite their being subject to delay. This behaviour differs significantly from that observed with fish which have stopped of their own accord in a holding pool. The consequences of the imposed delay and the associated misdirected activity might be reflected in the efficiency of subsequent migratory and reproductive activities.

Ascent of the Fish Pass

With the exception of one fish, all successful ascendants continued to migrate through the fish pass after proceeding to levels above the first chamber at the ladder entrance. The exceptional fish ascended to the sixth chamber of the pass, then left the structure by the bottom entrance.

Descent from the Dam

Three classes of down-stream movement from the dam have been described. In general, the timing of the major down stream movements (those greater than 10 km) coincided with periods of reduced power generation. During these periods tagged fish often entered the outlet draught tube of the operational turbine, these activities being most commonly recorded in May and early June. Fish returning down stream in this way remained below the dam for a shorter period of time (range 2-6 d) than those which subsequently passed through the fish ladder and continued up stream (range 0.6-43 d). No fish returned down stream after an intermediate or long period of residence below the dam. This might indicate that recent arrivals below the dam are more prone to return down stream than are fish which remain below the dam for some time.

The possibility that these down-stream movements may have been linked with entry to the draught tubes cannot be discounted. However, none of the activities observed could be linked or correlated to a specific event during the routine operation of the site (eg the timing of turbine changes etc). In discussing the design of HEPS discharging directly into a river channel or via a very short tailrace, Aitken *et al.* (1966) suggested that fish may be able to enter turbine draught tubes while they are operating at very light loads. Screening the outlets or constantly running the turbines continuously at relatively high generating loads were recommended as ways of inhibiting the entry of fish to the draught tubes.

The detailed movements of tagged fish could not be recorded within the confines of the draught tubes. It is not clear how close the fish came to the turbine blades. Mean water velocities *ca* 2.5 m below the turbine blades, over the period when this behaviour occurred, ranged from approximately 1.5 to 4.0 m $s^{-1}$ (Sturrock, personal communication). At water temperatures below 8 and 15°C, adult salmon 0.70—1.0 m in length would have burst swimming capacities (Wardle, 1980) in excess of these water velocities (Wardle, personal communication). However, turbulence within the draught tube immediately below the turbine may impair the swimming capabilities of the fish.

Long-range descent from the dam was not associated with flows significantly above the seasonal norm. Simultaneous tracking studies within other parts of the Tay system revealed only one of 22 radio-tagged fish moving down stream in the matter described. Apart from activities associated with spawning (Webb and Hawkins, 1989), down-stream movement within river channels has usually been recorded only during periods of significantly elevated discharge (Hawkins and Smith, 1986; Webb, 1989), in the area of tributary confluences (Webb, unpublished observations) and below natural obstructions (G.W. Smith *et al.*, unpublished observations).

Radio-tracking studies in summer 1987 (Webb, 1989) indicated that a decline in tributary flows to normal summer levels often resulted in migrants returning down stream to the main Tay at Islamouth. However, it is unlikely that the long-range down-stream movements (class 3, see p.13 ) shown by some of the radio-tagged fish in this study were a response to the seasonal decline in generating flows emerging from the dam *per se* for the following reasons:

(i) The longer range movements did not coincide with levels of flow significantly less than those associated with the earlier, up-stream movements of the same fish through the lower Tummel to the dam (Table IV) or, where applicable, during the course of the other two classes of temporary down-stream movement (classes 1 and 2, see p.13 ).

(ii) None of the cases of long-range descent was obviously associated with a reduction in flow (over the course of any particular day) owing to a change in the level of hydro-electric power generation (Fig. 7a–d). Furthermore, in most cases the timing of the initiation of movement down stream was at a level of flow approximately equal or greater than had been recorded over the previous 24 h (Table VI; Fig. 7a–d).

(iii) Migrants failed to resume their up-stream migration during the course of the significantly increased levels of main river and tributary flow recorded later in the summer (Tables III, IV and V) whereas the five migrants that successfully negotiated the fish ladder together with the other radio-tagged fish distributed elsewhere in the river system did so.

Several instances of down-stream movement by tagged fish within the Dee were attributed to the fish being either dead or in a distressed state during a furunculosis epidemic (G.W. Smith *et al.*, unpublished observations). However, the disproportionate frequency of this behaviour shown by fish ascending the River Tummel to Pitlochry dam, relative to that of the other tagged fish distributed elsewhere in the Tay system at the same time, suggests that this is an unlikely explanation.

It is conceivable that the radio tags were regurgitated by the fish at the dam site and subsequently drifted down stream. Tag regurgitation has been observed by a few fish immediately after tagging, or during capture by angling. During the course of similar studies undertaken in the Rivers Dee and Spey (1985-1989, inclusive) a total of 125 salmon and grilse was tracked. Confirmed cases of tag regurgitation accounted for only 4% of the fish monitored over this period, the Floy-tagged fish subsequently being recaptured elsewhere. Despite the wide range of seasonal flows recorded during the aforementioned studies, the down-stream movement of the regurgitated radio tag was not observed in any of the five recorded cases (G.W. Smith and R. Laughton, personal communication). The experiments described in this paper, where radio tags released into the river failed to move down stream, suggest that tag regurgitation is not a likely explanation for the down-stream movements of salmon observed in the Tay.

As no carcases were found it is impossible to be certain of the fate of the fish that moved down stream from the dam. However, as it has been shown that fish can and do enter the draught tubes and that any regurgitated tags do not move down stream, it seems likely therefore that fish moving down stream in an uncharacteristic manner were in a distressed state and may have died subsequently. The high proportion of fish reaching the dam which then moved down stream is a cause for concern, and requires further investigation.

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**Summary** The movements of 11 radio-tagged salmon ascending the River Tay and its largest tributary, the Tummel, in the spring and early summer of 1988 are described. Fish caught by sweep net in the river estuary were returned to the river after conventional tagging and the insertion of a radio tag. Migration up stream was recorded over a range of main-stem and tributary flows, and continued to Pitlochry dam near Port-na-Craig.

Detailed observations were made of the behaviour of tagged individuals in the river immediately down stream of the dam. The fish delayed their up-stream progress, remaining in the dam tailrace or in a series of pools immediately downstream of the dam for varying periods of time. The radio-tag signal of one fish was lost eight days after arriving at the dam. Subsequent activity at the dam tended to take place in areas of the channel where heavy water flows were emerging from the turbines rather than those where the discharge from the fish pass entered the river. During periods of single turbine operation and reduced hydro-electric power generation, tagged fish repeatedly entered the functional draught tube and remained there for varying periods of time. This activity was not observed during periods of significantly higher levels of power generation, normally employing two turbines.

After encountering the dam, most tagged fish moved down stream. Down-stream movements of greater than 10 km were recorded for five fish and they did not return up stream. Such movements coincided with other tagged fish repeatedly entering the draught tube (from which the generating flows were emerging) during periods of single-turbine reduced power generation.

Five of the 11 fish which reached the dam successfully negotiated the fish ladder and surmounted the dam.

## References


**Aitken, P.L., Dickerson, L.H., Menzies, W.J.M.** 1966. Fish passes and screens at power works. *Proceedings of the Institute of Civil Engineers*, **35**, 26—57.

**Aprahamian, M.W., Strange, C.D. and Dimond, C.** 1988. Movements of Atlantic salmon, *Salmo salar* L., into the river Usk, South Wales, in relation to water quality. *Journal of Fish Biology*, **33** (Supplement A), 245—247.

**Baxter, G.** 1961. River utilisation and the preservation of migratory fish life. *Proceedings of the Institute of Civil Engineers*, **18**, 225—244.

**Beach, M.H.** 1984. Fish pass design - criteria for the design and approval of fish passes and other structures to facilitate the passage of migratory fish in rivers. *Fisheries Research Technical Report, MAFF Directorate of Fisheries Research, Lowestoft*, (78), 46pp.

**Calderwood, W.L.** 1909. The Salmon Rivers and Lochs of Scotland. London, Edward Arnold, 442pp.

**Calderwood, W.L.** 1930. Salmon and Sea Trout. London, Edward Arnold, 242pp.

**Calderwood, W.L.** 1946. The Pitlochry salmon pass: new ideas to be incorporated in the Tummel-Garry project. *Salmon and Trout Magazine* No. 117, 122—128.

**Cragg-Hine, D.** 1985. The assessment of the flow requirements for the upstream migration of salmonids in some rivers of North-West England. *I.S. Alabaster ed. Habitat Modification and Freshwater Fisheries.* Proceedings of EIFAC Symposium, Aarhus, 1984. London, butterworths; 209—215.

**Dunkley, D.A. and Shearer, W.M.** 1982. An assessment of the performance of a resistivity fish counter. *Journal of Fish Biology*, **20,** 717—737.

**Gardiner, M.L.** 1971. Recent changes in the movements of adult salmon *Salmo salar* L. in the Tay-Tummel-Garry system, Scotland. *Journal of Fish Biology*, **3**, 83—96.

**Hawkins, A.D. and Smith, G.W.** 1986. Radio-tracking obervations of Atlantic salmon ascending the Aberdeenshire Dee. *Scottish Fisheries Research Report*, **36**, 24pp.

**Jones, J.W.** 1959. The Salmon. London, Collins, 192pp.

**Laughton, R.** 1989. The movements of adult salmon within the River Spey. *Scottish Fisheries Research Report* , **41**, 19pp.

**Liscom, K.L., Mohan, G.E. , Stuehrenberg, L.C. and Wilder, P.J.** eds. 1985. Radio-tracking studies of adult chinook salmon and steelhead trout at Lower Columbia River hydro-electric dams, 1971-1977. *NOAA Technical Memorandum* NMFS F/NWC-81.

**Menzies, W.J.M.** 1931. The Salmon - Its Life Story. London, Blackwood & Sons Ltd, 210pp.

**Menzies, W.J.M. and Pentelow, F.T.K.** 1965. Fisheries and the development of hydro-electric power in Scotland. *International Council for the Exploration of the Sea,* CM 1965, No. 2, 8pp.

**Mills, D.H.** 1968. Some observations on the upstream movements of adult Atlantic salmon in the River Conon and River Meig, Ross-shire. *International Council for the Exploration of the Sea,* CM 1968/M:10, 5pp.

**Peters, J.C., Farmer, H.R. and Radford, P.J.** 1973. A simulation model of the upstream movement of anadromous salmonid fish. *Reading, Water Resources Board*, 76pp.

**Potter, E.C.E.** 1988. Movements of Atlantic salmon *Salmo salar* L., in an estuary in south-west England. *Journal of Fish Biology*, **33** (Supplement A), 153—159.

**Pyefinch, K.A. and Mills, D.H.** 1963. Observations on the movements of Atlantic salmon *(Salmo salar* L.) in the River Conon and the River Meig, Ross-shire. I. *Freshwater and Salmon Fisheries Research*, **31**, 18pp.

**Solomon, D.J. and Potter, E.C.E.** 1988. First results with a new estuarine fish tracking system. *Journal of Fish Biology*, **33** (Supplement A), 127—132.

**Stewart, L.** 1972. Environmental engineering and monitoring in relation to salmon management. *Proceedings of International Atlantic Salmon : Management, Biology and Survival of the Species*, 4 (1), 297—313.

**Struthers, G.** 1984. Comparison of adult salmon returns in the River Tay net-and-coble and rod fisheries for salmon smolt tagging experiments in two tributaries of the river Tay, Scotland. *International Council for the Exploration of the Sea*, CM1984/M:21, 9pp.

**Struthers, G.** 1985. Radio-tracking studies on the migratory behaviour of adult salmon in the upper Tummel, a Scottish river harnessed for hydro-electric generation. *International Council for the Exploration of the Sea*, CM 1985/M16, 6pp.

**Sturrock, R.M.R.** 1989. Regulation of releases from reservoirs. Gregory, J. ed. Water Schemes for the Safeguarding of Fisheries. Proceedings of a Workshop held at University of Lancaster, April 1988. Atlantic Salmon Trust Ltd.

**Wardle, C.S.** 1980. Effects of temperature on the maximum swimming speeds of fishes. *All, M.A. ed. Environmental Physiology of Fishes.* New York and London, Plenum Press, 519—531.

**Webb, J.** 1989. The movements of adult Atlantic salmon in the River Tay. *Scottish Fisheries Research Report*, **44**, 32pp.

**Webb, J. and Hawkins, A.D.** 1989. The movements and spawning behaviour of adult salmon in the Girnock Burn, a tributary of the Aberdeenshire Dee, 1986. *Scottish Fisheries Research Report,* **40**, 41pp.

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